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Management effects on biomass and foliar nutritive value of *Robinia pseudoacacia* and *Gleditsia triacanthos* f. *inermis* in Arkansas, USA

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Abstract

The browse potential of black locust (*Robinia pseudoacacia* L.) and thornless honey locust [*Gleditsia triacanthos* f. *inermis* (L.) Zabel] has not been adequately tested. Our objective was to determine effects of fertilization and pollarding on biomass and foliar nutritive value in separate studies of black locust and thornless honey locust in Arkansas, USA. Shoots were sampled monthly for two consecutive growing seasons in 2002 and 2003 to determine foliar, shoot, and total aboveground biomass, shoot basal diameter, and foliar nutritive value (crude protein and *in vitro* digestibility). Black locust yielded more foliar biomass when pollarded at 50 or 100 cm and fertilized with 600 kg P ha^{-1}, than at 5 cm with or without P, averaging 3.5 Mg dry matter ha^{-1}. Black locust foliar crude protein and *in vitro* dry matter digestibility ($\leq$170 and 534 g kg^{-1}, respectively) decreased as leaves aged, but still met maintenance needs for beef cattle (*Bos taurus* L.). Thornless honey locust had little agronomic potential because of slow establishment, low foliar yield (330 kg ha^{-1}), and a 2% reversion to undesirable thorny phenotype. Black locust should be considered for livestock browse when drought induces semi-dormancy of herbaceous forages.

Introduction

Black locust (*Robinia pseudoacacia* L.) and honey locust (*Gleditsia triacanthos* L.) are common, medium-sized tree legumes characterized by moderate to rapid growth rates, drought tolerance, shade intolerance, and thorns (stipular thorns in black locust and modified shoots in honey locust). Four-year-old black locust trees fix as much as 25.8 g N $tree^{-1}$ $year^{-1}$ (Danso et al. 1995). Honey locust does not form root nodules and apparently lacks the ability to fix atmospheric N_2 (Gold and Hanover 1993). *Gleditsia triacanthos* f. *inermis* (L.) Zabel, a thornless variant of honey locust, has been widely planted for landscaping but its browse potential is largely unknown. Thornlessness is probably an essential trait for acceptance by livestock producers, many of whom eradicate wild honey locust because of its numerous, thick thorns (typically 5 to 8 cm long) formidable enough to inflict personal injury and penetrate tractor tires. By contrast, black locust thorns are typically $\leq$2 cm long.

Black locust and honey locust forage had the highest ruminal digestibility and N availability among 10 hardwood species tested

(Baertsche et al. 1986). Black locust had better establishment and tolerance to sheep (*Ovis aries* L.) grazing marginal land in semiarid Greece than honey locust (Ainalis and Tsiouvaras 1998). Black locust contains at least one cytotoxic flavanoid (Tian and McLaughlin 2000) and can induce non-fatal poisoning of the horse, *Equus caballus* L. (Ball et al. 1996). Further, black locust foliage has phenolic compounds (e.g., condensed tannins) that may reduce in vivo crude protein digestibility and herbage intake compared to alfalfa meal (Ayers et al. 1996; Cheeke 1992). Goats (*Capra hircus* L.) fed black locust herbage in summer had similar live weight gain (>100g d^{-1}) as goats fed alfalfa pellets (Papachristou et al. 1999). Black locust cannot replace alfalfa for livestock preference or herbage quality, but could provide an ample, sustainable source of high quality livestock browse in areas where alfalfa may not be productive. Honey locust forage has no apparent toxic effects to livestock, but was not recommended for goat silvopasture (Addlestone et al. 1999) because of slow stem growth, insufficient herbage production, and slow coppice response compared to black locust and mimosa (*Albizia julibrissin* Durazz.).

Deep-rooted, perennial trees such as black locust and thornless honey locust could have a particular niche for rotational livestock browse when drought limits forage options and livestock productivity, as has been demonstrated for the sub-Mediterranean region (Papanastasis et al. 1998). Climatic conditions of the southeastern USA are generally favorable for high annual forage yields: an average frost-free growing season of 7 to 9 months and annual rainfall of 1000–1500 mm. Adequate rainfall and mild temperatures foster a bimodal distribution of forage from C_3 species in spring and fall, with less production in summer and winter. Locally, however, insufficient rainfall and high ambient air temperatures during summer months can induce semi-dormancy of C_3 and C_4 forage species, necessitating costly, supplemental hay feeding. Producers could substantially increase profit margins by developing forage systems that extend the grazing season, thus decreasing or eliminating the costs of harvesting and feeding hay.

The seasonal distribution of foliar biomass for tree legumes has not been sufficiently tested in the humid South. Our objective was to determine effects of fertilization and pollarding on biomass and foliar nutritive value in separate studies of black locust and thornless honey locust in Arkansas, USA.

Materials and methods

Experiments were conducted near Booneville, Arkansas (35°05′ N, 93°59′ W, 152 m a.s.l.) on a Linker fine, sandy loam soil (fine-loamy, siliceous, thermic Typic Hapludult). Woody and herbaceous surface vegetation were removed with a bulldozer, and the surface was tilled to 15 cm depth in February 2000. At initiation of the study, topsoil (15 cm depth) had pH 7.0. Available P in topsoil (Bray 1 method) was measured at termination of the test. Rainfall data for Booneville were obtained from NOAA (2002a). Pan evaporation data for Blue Mountain Dam, located 27 km west of the experimental site, were from NOAA (2002b).

Black locust

Black locust trees recolonized the site from existing roots. Trees were about 2 m tall at the end of the 2001 growing season when permanent plots (5.5 × 9m) were delineated. Phosphorus treatment was the main plot effect, with 0-46-0 fertilizer applied at 0 and 600 kg P ha^{-1} year^{-1} in December 2001 and 2002. Clipping height was the sub-plot effect, with dormant shoots clipped in December 2001 to 2003 at 5, 50, and 100 cm from soil surface. Dormant shoots clipped in December 2002 and 2003 from each plot were counted, weighed, and measured for length.

Plants clipped 5 cm above ground surface are actually coppiced while plants clipped at 50 and 100 cm height are pollards. For simplicity, however, the term ‘pollard’ will be used for all clipping treatments. Further, the term ‘shoot’ will be used to designate both the primary stem developing from plants clipped at 5 cm height, and axillary branches that arose from the primary stem in pollard treatments.

Once monthly from early June through early October 2002 and 2003, three shoots were selected at random from each plot. The three shoots were clipped at the same pollard height as the plot. Shoot basal diameter was measured 5 cm distal to the clipping height for 5 cm pollards, or 5 cm distal to the branch point for 50 and 100 cm pollards. Leaves (petioles and leaflets) were removed from the clipped shoots, including 5–10 cm of unlignified shoot apex. Foliar and shoot samples were dried at 60 °C for 48 and 120 h, respectively, and weighed. Foliar samples were ground to pass a 1 mm screen.

A composite foliage sample was created by pooling an equal-mass sub-sample from the three plants of each sampling date and plot. Nitrogen was determined by combustion on a Leco FP428 analyzer (Leco Corp., St. Joseph, Michigan). Crude protein was calculated as N percentage × 6.25. In vitro dry matter digestibility was analyzed using an ANKOM® Daisy II fiber analyzer #F200 (ANKOM Technology Corp., Fairport, New York). The rumen fluid for digestibility analysis was collected from a cannulated steer that had been fed bermudagrass (*Cynodon dactylon* L.) hay for at least 1 week prior to collection.

Yields of foliar biomass and shoot biomass were calculated from dry matter yield × total shoots and expressed on kg ha^{-1} basis. For any given harvest, yields of foliar biomass and shoot biomass represented an accumulation from the beginning of the growing season. Total aboveground biomass was the sum of foliar biomass and shoot biomass.

Thornless honey locust

The test was located adjacent to the black locust test on the same soil series. The site was initially prepared as described above. In March 2001, 2-year-old (1–1) bare root seedlings (Lawyer Nursery, Plains, Montana), 45–60 cm tall, were transplanted at 1.4 m spacing into furrows spaced 0.8 m apart created by deep (55 cm) tillage. Seedlings had either Illinois or Oregon, USA provenance (personal communication, 2000, Lawyer Nursery). We hypothesized that thornless honey locust would respond to N fertilization because it does not fix atmospheric N_2 (Gold and Hanover 1993). Nitrogen was applied as NH_4NO_3 (34-0-0) at 0, 75, and 150 kg ha^{-1} year^{-1} in split applications (one-half at bud-break on 19 April and one-half in early June 2002) to a plot containing 25 trees (4 × 7m). Bermudagrass, the primary herbaceous component of tree alleys, was controlled by mowing. Seedlings were sprayed weekly (from 1 August through 15 September 2002) with carbaryl (1-naphthyl *N*-methylcarbamate) at 0.15 kg a.i. ha^{-1} to control grasshoppers (Orthoptera: Acrididae). Grasshoppers were not a pest in 2003.

Once monthly from early June through early September 2002, shoot basal diameter and foliar biomass (petioles and leaflets) were measured on three trees plot^{-1}. Foliar dry weight, crude protein, and digestibility were measured as described above. Shoots were not clipped in this test to minimize stress on the saplings. The experiment was repeated in 2003.

Statistical analysis

Tests were conducted separately for black locust and thornless honey locust so means were not directly comparable. The black locust test was a split-plot design with two replicates. Phosphorus treatment was the main plot and pollard height the sub-plot. Harvest date, P treatment, pollard height within P treatment, and their interactions were fixed effects; year, replication, and their interactions were random effects. Data were transformed by natural logarithm (*ln*) to adjust for heteroscedasticity (Steel and Torrie 1980) before analysis of variance with a mixed linear model of SAS® (Littell et al. 1996). When *F*-tests were significant at $p \leq 0.05$, data were back-transformed by anti-logarithms for presentation.

The thornless honey locust test was a randomized complete block design with three replications. Data were analyzed with a mixed linear model (Littell et al. 1996). Harvest date, *N*-rate, and harvest date × *N*-rate were fixed effects; year, replication, and their interactions were random effects. Tests of significance of mean squares were not affected by *ln*-transformation, so analysis of variance was conducted on untransformed data. Unless otherwise indicated, effects were considered significant in all statistical calculations if $p \leq 0.05$.

Results

Environmental conditions during the growth interval in 2002 and 2003 were generally drier than normal, although rainfall in August 2002 and 2003 was above average (Table 1). Pan evaporation usually exceeds rainfall during June to September. At termination of the black locust test, topsoil available P was nearly twice as high in plots receiving fertilizer P (143.7 $\mu g\ g^{-1}$) compared to those without P fertilization (67.8 $\mu g\ g^{-1}$). The thornless honey locust test had 93.6 μg P g^{-1}. Available P was considered non-limiting for forage production.

Black locust

There were about 13,800 trees ha^{-1} in December 2001, at initiation of the test, and 15,000 trees ha^{-1} in December 2002 and 2003. Shoot number, weight,

Table 1. Rainfall and evaporation (in mm) during the study period for Booneville, Arkansas.

Month	Rainfall		Long-term rainfall[a]	Long-term pan evaporation[b]
	2002	2003		
June	74.3	128.4	107.2	141.7
July	68.2	31.9	89.2	170.7
August	77.6	102.0	59.4	160.9
September	56.0	55.0	102.6	110.1
October	80.8	28.1	99.1	62.3

[a]Data for Booneville, 1971–2000 (NOAA 2002a).
[b]Data for Blue Mountain Dam, 1979–2001 (NOAA 2002b). Recording station is about 27 km west of the experimental site.

and shoots $tree^{-1}$ were influenced by pollarding. Number of dormant shoots increased significantly with pollard height in the order $15{,}400 < 36{,}900 < 45{,}400$ shoots ha^{-1} (or $2.7 = 2.2 < 4.5$ shoots $tree^{-1}$) at 5, 50, and 100 cm, respectively. The increase in shoot number was achieved at a cost of decreasing shoot diameter ($18.8 > 17.8 = 17.4$ mm) and weight ($162 > 81 = 60$ g $shoot^{-1}$) at 5, 50, and 100 cm, respectively. Shoot length (2.2 m) was unaffected by main effects or their interaction ($p \geq 0.14$).

Foliage, shoot, and total aboveground biomass were significantly affected by harvest date, P treatment, and pollard height within P treatment, but not by interactions of harvest date with P treatment or pollard height ($p \geq 0.43$). There was more foliar and total biomass in August than at earlier harvest dates (Figure 1). Foliar biomass decreased from August to October with onset of leaf senescence. Shoot biomass was greater in September than at earlier harvest dates. Across treatments, black locust yielded about 124 g foliage dry matter $shoot^{-1}$ $year^{-1}$ (3500 kg ha^{-1}), and shoots averaged about 2 m growth at the end of each growing season.

Biomass was affected by pollard height within levels of P. Fertilization with P significantly increased foliar, shoot, and total biomass for 5 and 100 cm pollards, but there was no corresponding increase at 50 cm (Figure 2). Across pollard treatments, P fertilization increased production of

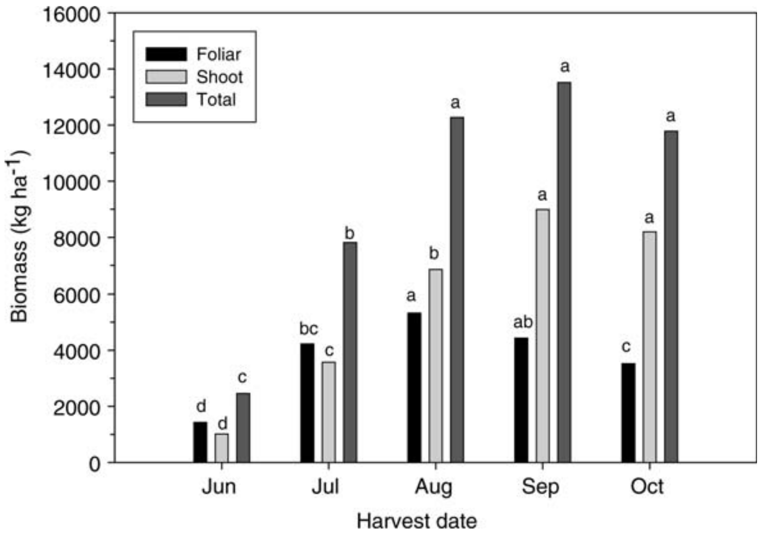

Figure 1. Effect of harvest date on black locust foliar, shoot, and total aboveground biomass in Arkansas, USA. A common letter above bars for each biomass component indicates means do not differ by paired *t*-test ($p \leq 0.05$).

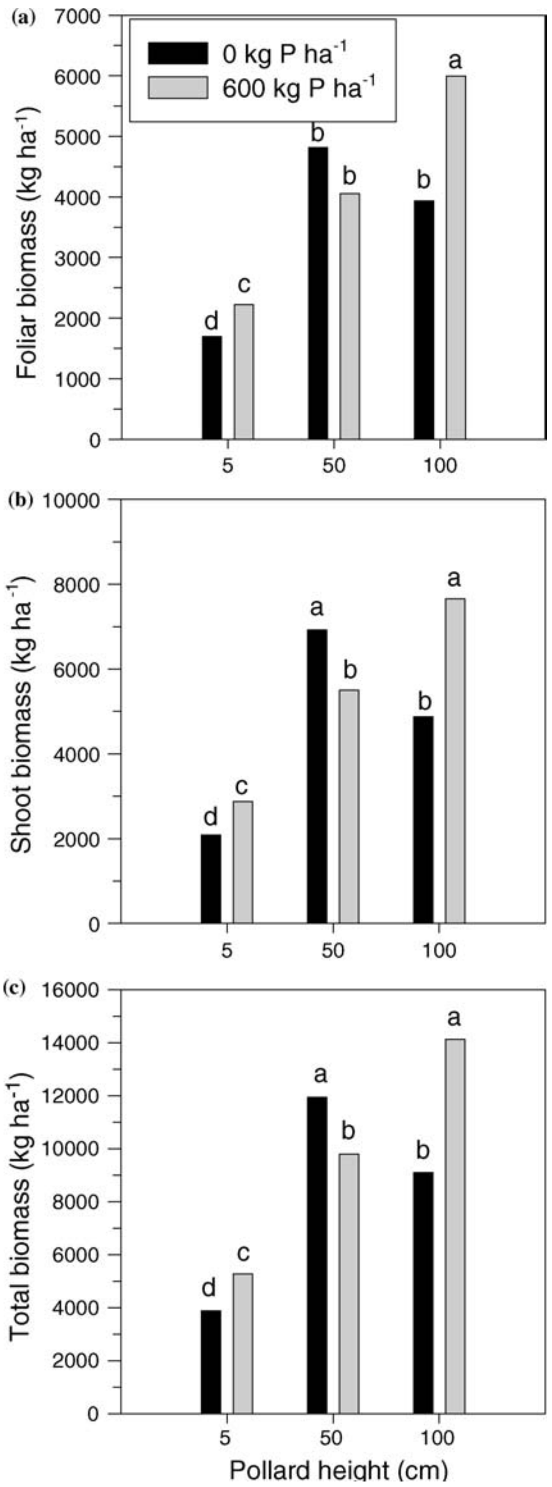

Figure 2. Effect of pollard height and P treatment on black locust foliar (a), shoot (b), and total aboveground biomass (c) in Arkansas, USA. A common letter above bars indicates means do not differ by paired *t*-test ($p \leq 0.05$).

each biomass component nearly 20%. The basis for this P effect was not clear because neither number nor weight of dormant shoots were significantly affected by P treatment.

Foliar crude protein was significantly affected only by harvest date. There was a linear decrease of herbage crude protein from 239 to 170 g kg^{-1} across the growing season (Figure 3a). Herbage digestibility was significantly affected by pollard height within P treatment, with 100 cm pollards from the no-P treatment having greater digestibility (589 g kg^{-1}) than the other pollards (561 to 575 g kg^{-1}). There was a non-linear response of digestibility with harvest date, decreasing from June (663 g kg^{-1}) to September (534 g kg^{-1}) and increasing to 557 g kg^{-1} in October (Figure 3b).

Thornless honey locust

Shoot basal diameter and foliar dry weight were significantly affected by harvest date and N treatment, but not by the interaction of harvest date and N treatment. Shoot basal diameter (Table 2) increased from June (15.1 mm) to August (19.6 mm) but decreased in September (15.3 mm). The decrease in September appeared to be caused by shoot dieback followed by basal sprouting, and not necessarily indicative of a seasonal trend. Foliar dry weight was lower in September than at previous sampling dates because of onset of leaf senescence. Shoot basal diameter and foliar yield were greater at 75 kg N ha^{-1} than at other *N*-rates (Table 3). Across treatments, thornless honey locust yielded about 37 g foliage tree^{-1} year^{-1}, or 330 kg ha^{-1}. Trees were $\leq$1 m tall after 2 year growth.

Crude protein was influenced by harvest date. Crude protein (Table 2) varied little from June to August ($\geq$125 g kg^{-1}), but decreased from August to September due to onset of leaf senescence. Nitrogen treatment did not affect ($p \geq 0.26$) herbage nutritive value. There were no significant treatment effects on foliar digestibility which, for this germplasm, averaged 628 g kg^{-1}.

Of the 400 thornless honey locust trees planted at this site (including buffers), eight (2%) reverted from thornless to thorny phenotype during the study. These variants had a range of thorniness ranging from scarce, short thorns to typical wild type.

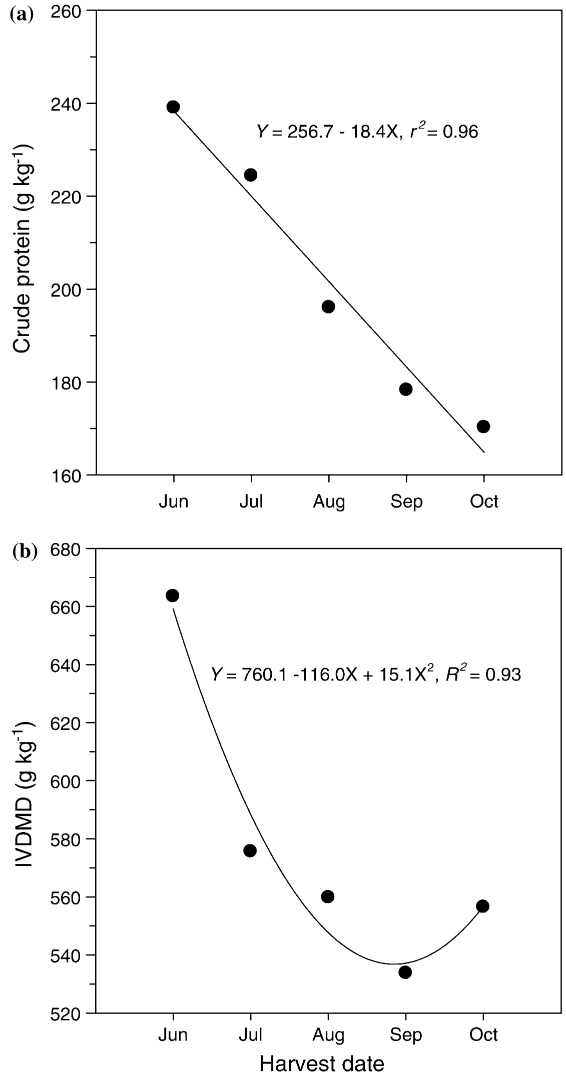

Figure 3. Effect of harvest date on nutritive value of black locust herbage in Arkansas, USA. (a) Crude protein, (b) In vitro dry matter digestibility. Harvest dates were arbitrarily numbered as June = 1, July = 2… October = 5 for regression.

Discussion

Western Arkansas typically experiences hot, dry climatic conditions in July and August (NOAA 2002a, b) that cause the predominant C_3 and C_4 forage species [tall fescue (*Festuca arundinacea* Schreb.) and bermudagrass, respectively] to become semi-dormant. For producer acceptance, yield of alternative forages must be comparable to these species during this period. Tall fescue and bermudagrass harvested monthly yield about 1000 kg DM ha^{-1} in August in this region (Baker 2000; Burke et al. 2004). By contrast, black locust yielded 5300 kg ha^{-1} of accumulated foliage when harvested in August (Figure 1). Thornless honey locust yielded 44 g tree^{-1} (390 kg ha^{-1}) in August. Thus, pollarded black locust could be used to ameliorate forage deficits in August.

Table 2. Effect of harvest date on crude protein, foliar dry weight, and shoot basal diameter of thornless honey locust in Arkansas, USA.

Harvest date	Shoot basal diameter (mm)	Foliar dry weight (g tree^{-1})	Crude protein (g kg^{-1})
June	15.1 b^{A}	43.2 a	124.9 ab
July	16.3 b	44.0 a	133.5 a
August	19.6 a	44.1 a	134.5 a
September	15.3 b	17.7 b	112.3 b

^{A}Means within columns followed by the same letter do not differ by paired *t*-test ($p \geq 0.05$).

Table 3. Effect of N treatment on foliar dry weight and shoot basal diameter of thornless honey locust in Arkansas, USA.

N treatment (kg ha^{-1})	Shoot basal diameter (mm)	Foliar dry weight (g tree^{-1})
0	15.8 b^{A}	34.4 b
75	17.9 a	48.3 a
150	16.0 b	29.0 b

^{A}Means within columns followed by the same letter do not differ by paired *t*-test ($p \geq 0.05$).

Propagation method, i.e., root coppices of black locust and transplanted seedlings of thornless honey locust, confound growth and yield differences between the two species. In a separate study (D.M. Burner, 2004, unpublished data), stem growth was measured for three species 1 year after pollarding at 15 cm (2 year after transplanting). Thornless honey locust stems averaged 3 g dry weight tree^{-1}, compared to black locust and mimosa which averaged 50 and 33 g tree^{-1}, respectively ($p \leq 0.05$). Thus, our tentative data supported Addlestone et al. (1999), who found that honey locust was slower growing than black locust.

High biomass yields during summer may be due to black locust having adaptive drought-resistance strategies such as deep rooting and low leaf to root dry weight ratio (Ranney et al. 1990). Cultural practice affected dry matter partitioning in black locust. Fertilization with 600 kg P ha^{-1} increased dry matter allocation to foliage and shoots of 5 and 100 cm pollards compared to no fertilization, even though available soil P in the unfertilized plots seemed to be adequate (Figure 2). However, foliar biomass decreased from August to October as leaves senesced.

Foliage of thornless honey locust senesced in September, earlier than most woody plants of the region. Northern provenances of honey locust have a genetic predisposition for early leaf abscission and stem dieback (Gold and Hanover 1996). Water stress also causes early leaf abscission and slow growth of thornless honey locust (Smitley and Peterson 1996). Sapling trees of thornless honey locust probably had small root mass, predisposing them to drought stress in July and August. Reversion to thorniness indicates that the thornless trait was phenotypically unstable in the germplasm. Further, thornless varieties can produce substantial quantities of thorny progeny via seed (Csurhes and Kriticos 1994). The risk of pasture invasion by thorny types might be unacceptable to producers. Our data on N response were consistent with those of Chong (2000), who reported that basal stem diameter of 2-year-old thornless honey locust seedlings responded to N fertilization.

Tall fescue and bermudagrass have relatively high nutritive value, accounting, in part, for their widespread use. In August, tall fescue typically has 113 g kg^{-1} crude protein and 593 g kg^{-1} digestibility (Matches 1979), and bermudagrass has 131 g kg^{-1} crude protein (Baker 2000) and 500–550 g kg^{-1} digestibility (Ball et al. 1996). We found that black locust foliage in August had 195 g kg^{-1} crude protein and 557 g kg^{-1} digestibility, and thornless honey locust had 134 g kg^{-1} crude protein and 628 g kg^{-1} digestibility. These levels are roughly comparable to previous reports (Baertsche et al. 1986; Papachristou et al. 1999). Thus, black locust could supply an alternative source of nutritious forage during summer.

Nutritive value decreased across the growth interval (Figure 3). A seasonal decrease in foliar N and P accompanying leaf aging has been observed for black locust and honey locust, as nutrients are resorbed by bark tissue (Vogel and Dawson 1993). However, even late in the season the nutritive value of black locust foliage was at least comparable to that of fall-harvested tall fescue receiving high rates of N fertilization (D.M. Burner, 2004, unpublished data).

The feed value of black locust leaves has been debated in the literature. Black locust was suggested to have considerable feed potential based on chemical composition, herbage digestibility (including N digestibility), and animal live weight gain (Baertsche et al. 1986; Papachristou et al. 1999). Conversely, low nutritive value (digestibility, N digestibility, and tannins) and low animal weight gain argue against use of black locust for livestock feed (Cheeke 1992). These studies also compared nutritive value of alfalfa and black locust, which has little applicability in areas where alfalfa is not economically or sustainably produced. Preliminary data on a subset of August harvested foliage indicated that N digestibility of black locust (54%) and thornless honey locust (81%) tended to be less than that of two C_3 grasses [orchardgrass (*Dactylis glomerata* (L.) and tall fescue] (98 to 99%), bermudagrass (92%), and mixed C_3 and C_4 grass herbage (93%). An adequate intake of black locust foliage with 50% available N would meet minimum crude protein needs for growing and finishing cattle (NRC 1996). Clearly, trials are needed to compare performance of cattle and sheep grazing black locust leaves vs. locally available herbaceous forage.

Conclusion

In assessing the potential fodder value of black locust and thornless honey locust, managers need to consider apparent differences in anti-quality factors, rates of establishment, pollard responses, and, for thornless honey locust, possible reversion to thorniness. We were not encouraged by the apparent slow growth of thornless honey locust and its tendency for reversion to thorniness, but we tested only one germplasm source. Other genetic stocks of thornless honey locust should be examined for fodder yield, pollard response, and phenotypic stability. Black locust and thornless honey locust both exhibited a seasonal decrease in nutritive value, possibly due to leaf aging, although fodder quality met minimum maintenance levels for cattle. Black locust could broaden forage options for livestock producers by providing a high-yield, high-quality source of livestock browse when drought induces semi-dormancy of herbaceous forages.

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References

Addlestone B.J., Mueller J.P. and Luginbuhl J.-M. 1999. The establishment and early growth of three leguminous tree species for use in silvopastoral systems of the southeastern USA. Agroforest. Syst. 44: 253–265.

Ainalis A.B. and Tsiouvaras C.N. 1998. Forage production of woody fodder species and herbaceous vegetation in a silvopastoral system in northern Greece. Agroforest. Syst. 42: 1–11.

Ayers A.C., Barrett R.P. and Cheeke P.R. 1996. Feeding value of tree leaves (hybrid poplar and black locust) evaluated with sheep, goats and rabbits. Anim. Feed Sci. Technol. 57: 51–62.

Baertsche S.R., Yokoyama M.T. and Hanover J.W. 1986. Short rotation, hardwood tree biomass as potential ruminant feed-chemical composition, nylon bag ruminal degradation and ensilement of selected species. J. Anim. Sci. 63: 2028–2043.

Baker J.L. 2000. 1999 Forage yields from bermudagrass varieties and strains. Publ. NF-FOR-00–05. Noble Found. Inc., Ardmore, Oklahoma, USA.

Ball D.M., Hoveland C.S. and Lacefield G.D. 1996. Southern Forages, 2nd ed. Potash and Phosphate Inst., Norcross, Georgia, USA.

Burke J.M., Brauer D.K. and Looper M.L. 2004. Use of novel endophyte-infected tall fescue for cow–calf production in Arkansas. J. Anim. Sci. 82 (Suppl. 1): 91.

Cheeke P.R. 1992. Black locust forage as an animal feedstuff. In: Hanover J.W. et al. (eds), Proc. Int. Conf. Black Locust Biol., Culture, Utiliz., 17–21 June 1991. E. Lansing, MI, pp. 252–258.

Chong C. 2000. Response of little-leaf linden and honey locust to rates of organic and mineral nitrogen. Hortscience 35: 144.

Csurhes S.M. and Kriticos D. 1994. *Gleditsia triacanthos* L. (Caesalpiniaceae), another thorny, exotic fodder tree gone wild. Plant Protect. Quart. 9: 101–105.

Danso S.K.A., Zapata F. and Awonaike K.O. 1995. Measurement of biological N_2 fixation in field-grown *Robinia pseudoacacia* L. Soil Biol. Biochem. 27: 415–419.

Gold M.A. and Hanover J.W. 1993. Honeylocust (*Gleditsia triacanthos*), a multipurpose tree for the temperate zone. Int. Tree Crops J. 7: 189–207.

Gold M.A. and Hanover J.W. 1996. Geographic variation patterns in phenological characteristics of honeylocust (*Gleditsia triacanthos* L.). In: Dieters M.J. et al. (eds), Tree Improvement for Sustainable Forestry. Proc. QFRI-IUFRO Conf., 27 October–1 November 1996, Caloundra, Queensland, Australia, pp. 79–80.

Littell R.C., Milliken G.A., Stroup W.W. and Wolfinger R.D. 1996. SAS System for Mixed Models. SAS Institute Inc, Cary, North Carolina, USA.

Matches A.G. 1979. Management. In: Buckner R.C. and Bush L.P. (eds), Tall fescue. Agron. Monogr. 20. ASA, CSSA, SSSA, Madison, Wisconsin, USA, pp. 171–199.

National Research Council (NRC). 1996. Nutrient Requirements of Beef Cattle 7th revised ed. National Academic Press, Washington DC, USA.

National Oceanic and Atmospheric Administration (NOAA) 2002a. Climatography of the United States No. 81, Arkansas. National Climatic Data Center, Asheville, North Carolina, USA.

National Oceanic and Atmospheric Administration (NOAA). 2002b. Cooperative Summary of the Day. TD3200, Central Region, CD-ROM. National Climatic Data Center, Asheville, North Carolina, USA.

Papachristou T.G., Platis P.D., Papanastasis V.P. and Tsiouvaras C.N. 1999. Use of deciduous woody species as a diet supplement for goats grazing Mediterranean shrublands during the dry season. Anim. Feed Sci. Technol. 80: 267–279.

Papanastasis V.P., Platis P.D. and Dini-Papanastasi O. 1998. Effects of age and frequency of cutting on productivity of Mediterranean deciduous fodder tree and shrub plantations. For. Ecol. Manage. 110: 283–292.

Ranney T.G., Whitlow T.H. and Bassuk N.L. 1990. Response of five temperate deciduous tree species to water stress. Tree Physiol. 6: 439–448.

Smitley D.R. and Peterson N.C. 1996. Interactions of water stress, honeylocust spider mites (Acari: Tetranychidae), early leaf abscission, and growth of *Gleditsia triacanthos*. J. Econ. Entomol. 89: 1577–1581.

Steel R.G.D. and Torrie J.H. 1980. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill, New York, USA.

Tian F. and McLaughlin J.L. 2000. Bioactive flavonoids from the black locust tree, *Robinia pseudoacacia*. Pharmaceut. Biol. 38: 229–234.

Vogel C.S. and Dawson J.O. 1993. Changes in tissue nitrogen and phosphorus and foliar free amino acids in autumn olive, black locust, American sycamore, and honey locust during autumn. Can. J. For. Res. 23: 665–672.